Effective dielectric permittivities for improved Finite-Difference Time-Domain modeling of photonic-crystal microresonators

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Theoretical study of light propagation in photonic crystals involves modulations of the dielectric permittivities on the subwavelength scale. As a result, simulations are usually quite challenging, in particular when dealing with microcavities with a high quality factor. Several numerical techniques have been applied from more developed fields, such as grating theory and microwave engineering. Among them, the Finite-Difference Time-Domain (FD-TD) method has gained increasing popularity in the research community because of its direct-solver algorithm and its flexibility in dealing with complex geometries. However, FD-TD exhibits two major drawbacks that are somewhat related each other. First, because the structure is usually defined on a cubic mesh, curved dielectric and metallic interfaces are not accurately modeled unless the mesh is very fine. Second, a finer mesh requires an increasingly large amount of memory and CPU time to run the simulation.

In this work, we show that also for curved dielectric interfaces it is possible to write effective permittivities that properly account for the electric field boundary conditions. By using these values, the convergence of the FD-TD solution is improved considerably in comparison with the staircase approximation or other simple volume-averaged effective permittivities. Therefore, accurate results become accessible with coarse meshes, allowing fast simulations without supercomputing resources. We will discuss numerical examples on designs of high quality factor photonic crystal microresonators.